Development and Demonstration of Medium- and Heavy-Duty PHEV Work Trucks

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Organization: Odyne Systems, LLC

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Project ID: elt094

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Project Overview

Timeline:

- Start Date: January 19, 2017
- Completion Date: January 31, 2023
- Percent Complete: 75%

Budget

- Total project funding: $6,955,281
  - DOE Share: $2,149,644
  - FFRDC Share: $ 782,549
  - Contractor Share: $4,023,088

- FY20 DOE Funding: $ 367,416
- FY21 DOE Funding: $ 378,133
  - *Includes FFRDC*

Barriers

- Fuel efficiency of Medium/Heavy-duty work trucks
- Integration of Driving and Jobsite electrification of Medium/Heavy-duty work trucks
- Over 50% of Work Truck fuel use occurs during stationary operation – not addressed by traditional Hybrid solutions

Project Partners

- Odyne Systems – Project Lead
- Freightliner Trucks
- Allison Transmission
- Ricardo Engineering
- National Renewable Energy Laboratory
- Oak Ridge National Laboratory
- South Coast Air Quality Management
- 2 Utilities - TBD

Any proposed future work is subject to change based on funding levels

Relevance / Objectives

- Overall Objectives
  - To develop and demonstrate an advanced Plug-in Hybrid Electric (PHEV) Medium-Heavy Duty Work Truck
    - With greater than 50% reduction in fuel consumption when compared to a conventional diesel vehicle baseline
- Relevance
  - Work trucks are unique in the proportion of fuel used during stationary activity and the diversity vehicle design and jobsite equipment utilized to fulfill their missions
  - Most hybrid work focuses on driving, ignoring the high stationary fuel use of the vocational market
  - This project will develop and demonstrate a modular PHEV Work truck solution which meets the needs of the work truck user while demonstrating a 50% reduction in full-day fuel use
- Milestones

Milestones: Period 2	Date	Status 5/14/21
Prototype Vehicle Functional Validation	October, 2019	Complete
Hardware in the Loop (HIL) Powertrain Verification	February, 2020	Complete
Prototype Vehicle Performance Validation (Go-No Go)	May, 2021	Finalizing Report
Evaluation Fleet Build and Delivery	December, 2021	On Track

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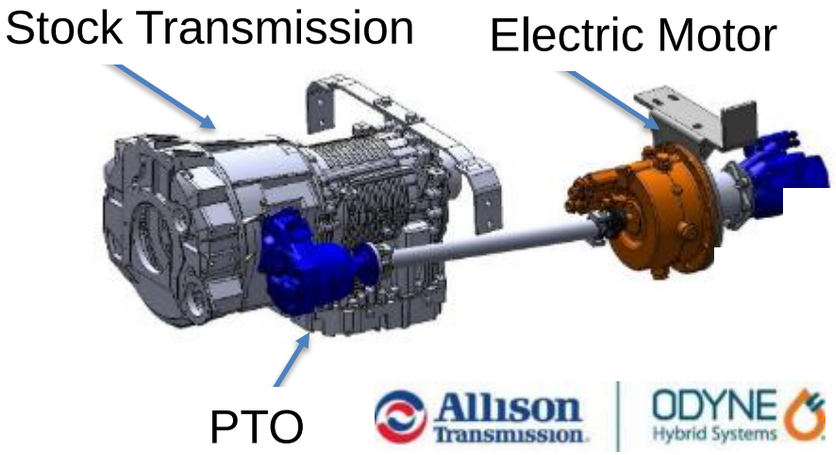
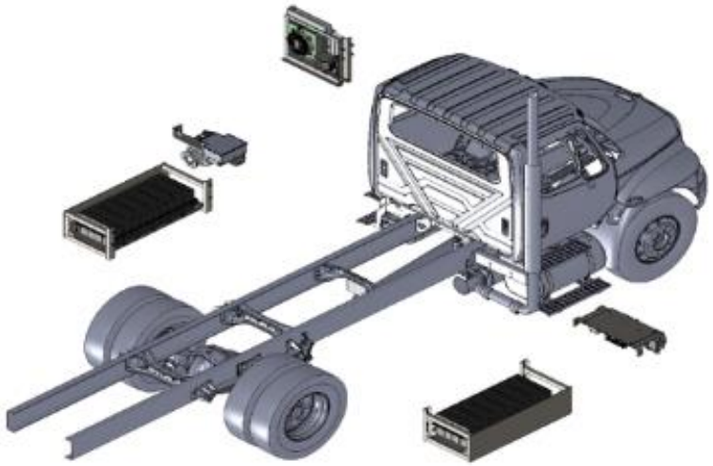
Approach:
Plug-in hybrid propulsion+ work site idle reduction

Hybrid Powertrain



Modular Design



Multiple Vocations

Minimally Intrusive

Hybrid Power through existing PTO port
No Changes to Base Powertrain
Allison Approved – Retains Powertrain Warranty

Flexible

60 kW of hydraulic/pneumatic power
15 kW of 120/240VAC exportable power
Multiple OEM and Application platforms
- Same base hybrid system

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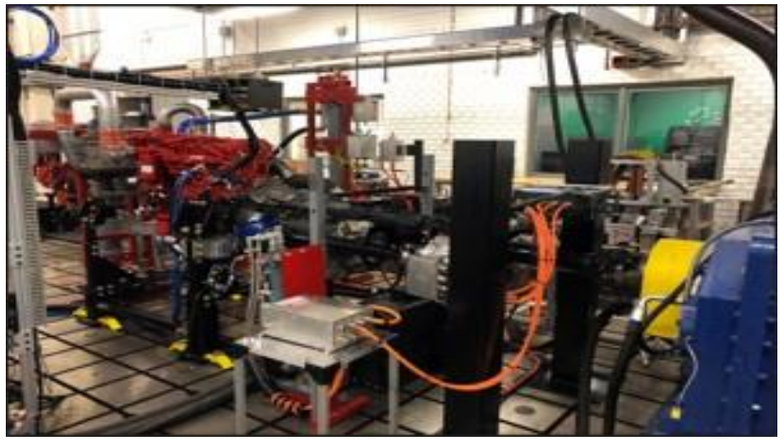
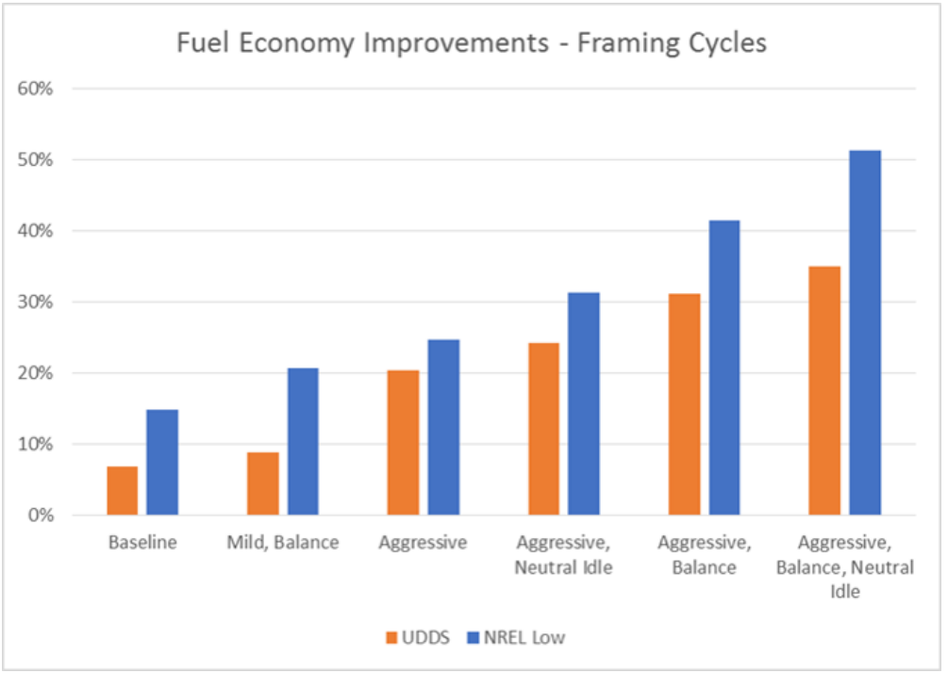
Technical Accomplishments
Powertrain Optimization

- Oak Ridge Simulation model was utilized to evaluate multiple iterations of refined Driving Strategies
- Oak Ridge Hardware-in-the-Loop (HIL) Powertrain Dynamometer was utilized to validate the simulation and fine tune the driving strategies
- Primary features resulting in improved fuel economy included:
  - Increasing speed (MPH) range of Torque Assist
  - Increasing Peak Torque Available
  - Balance mode, reduce engine load by the amount hybrid motor is providing
  - Idle Neutral
- Results
  - The combination of features above predicted fuel economy improvements of 34-51% over baseline diesel
  - Two strategies were chosen for chassis dyno test
    - Aggressive – All the features evaluated
    - Mild – Closer to charge sustaining strategies with lower battery use per mile



Hybrid Powertrain on Oak Ridge HIL Powertrain Dyno



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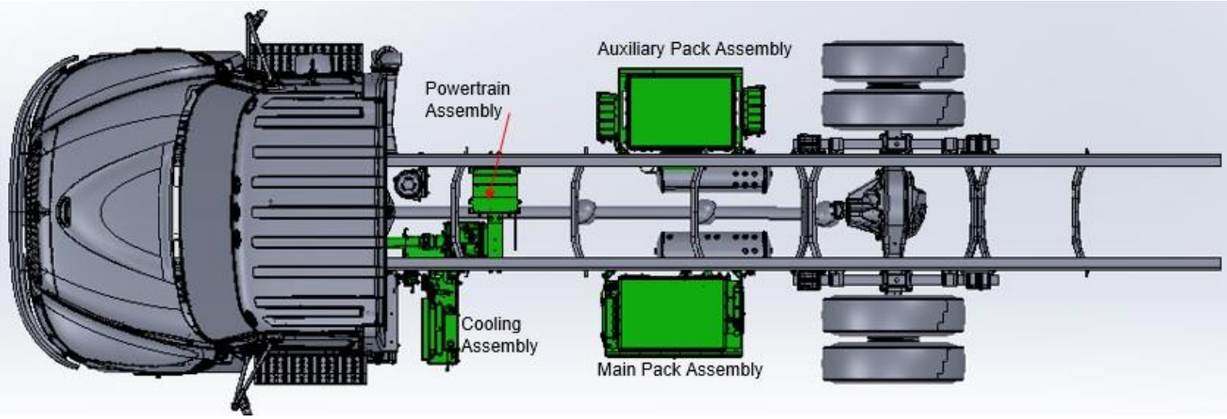
Technical Accomplishments
Finalize Design and Build Test Truck

- Design and integration into Test Chassis has been completed
  - Modular integration: 3 primary, 1 optional
- Final Subsystem Specifications:
  - 17.7 / 35.4kWh RESS
  - 250 Nm, 71 kW Peak, 150 Nm, 50 kW Continuous Motor Torque/Power
  - 12 kW Exportable Power (120V/240V)
  - 4 kW DC/DC 12V support
  - 3.3 kW J1772 Level 2 Charging
  - Independent WEG Cooling System
  - 17.000 btu Engine-off HVAC

Side view of completed test chassis



Plan View – Test Chassis Model with Hybrid modules

Top view of completed test chassis

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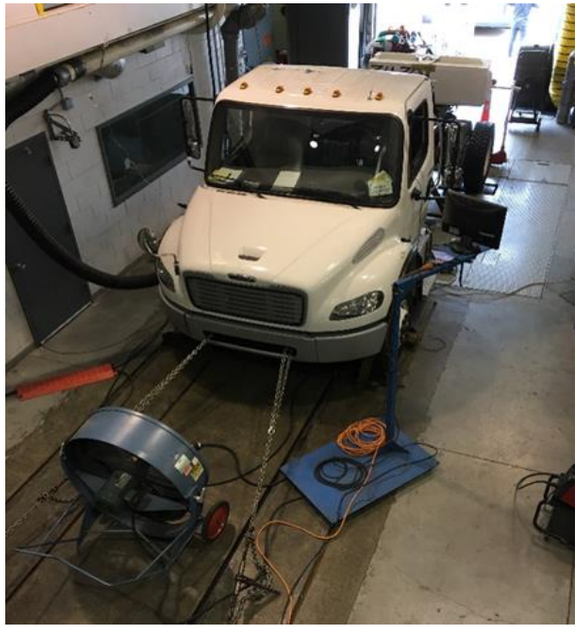
Technical Accomplishments
NREL System Test

- The Test Truck was tested at the NREL ReFUEL Dynamometer test facility
  - Mild strategy yielded 9.5 – 23% improvement in fuel economy
  - Aggressive strategy yielded 69 – 75 % improvement in fuel economy
  - **Stationary Work Cycle:** Hybrid system yielded 80-99% improvement in fuel consumption and emissions
    - Worst case scenario assuming all energy derived from field recharge



Test Truck on NREL ReFUEL Chassis Dyno

NREL Drive Cycle Test Results

Strategy	Duty Cycle	Distance [mi]	Fuel Used [gal]	Fuel Used Per Mile [gal]	MPG	MPG Improvement	Energy Used Per Mile [kWh]
Conventional	UDDS	5.503	0.892	0.162	6.174		0.000
Hybrid Mild	UDDS	5.498	0.813	0.148	6.762	9.5%	0.060
Hybrid Aggressive	UDDS	5.514	0.528	0.096	10.456	69.4%	0.971
Conventional	Odyne Low	3.782	0.809	0.214	4.678		0.000
Hybrid Mild	Odyne Low	3.780	0.656	0.174	5.758	23.1%	0.508
Hybrid Aggressive	Odyne Low	3.788	0.476	0.126	7.954	70.0%	1.675
Conventional	Odyne Medium	8.911	1.431	0.161	6.226		0.000
Hybrid Mild	Odyne Medium	8.907	1.226	0.138	7.266	16.7%	0.197
Hybrid Aggressive	Odyne Medium	8.897	0.815	0.092	10.918	75.4%	1.220

NREL Stationary Cycle Test Results

PTO shaft work specific results comparison				
	NOx	CO2	Fuel ConsCB	Fuel cons FS
	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
Conventional PTO first	51.303	4423.116	1390.698	1452.816
Conventional PTO - warm	62.001	4388.342	1380.650	1460.858
ePTO Cold Charge	1.248	920.246	283.250	315.853
ePTO Warm Charge	0.731	712.890	224.050	250.621
Improvement: cold	98%	79%	80%	78%
Improvement: Warm	99%	84%	84%	83%

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Collaborators /Team

Organization	Function
National Renewable Energy Laboratory	• Telematics Duty Cycle Analysis • Fuel & Emissions Dynamometer Testing • Full Year Fuel Use Modeling
Oak Ridge National Laboratory	• Powertrain Simulation, Energy use optimization • Hardware-in-Loop (HIL) Powertrain Testing
Freightliner Trucks	• Chassis System Integration assistance, Vehicle models • Investigating commercialization codes for Odyne System • Truck Supplier for Prototype truck
Allison Transmission	• Powertrain and transmission optimization support • Transmission Control System integration
Ricardo Strategic Sourcing	• Battery System Sourcing
Utilities (2-TBD)	• Provide 5 vehicles each for demo fleet • Participate in demo evaluation and feedback
South Coast Air Quality Management District	• Project cost share

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Responses, Barriers, Proposed Future Research

- Responses to Prior year comments
  - This project was not reviewed last year
- Remaining Barriers and Challenges
  - Changes in Utility priorities has made it difficult to find willing participants to donate capital equipment to the project for the period 3 demonstration
    - Odyne is working with DOE to revise the program plan to allow a depreciation cost-share rather than the full equipment, thus eliminating the capital burden on the Utility participants
- Proposed Future Research
  - Period 2: Complete full year simulation of work truck fuel savings based on NREL driving and stationary test results (In Process)
  - Period 2: Secure 2 Utility partners to partner with for Period 3 demonstration
  - Period 2: Assemble hybrid systems on Utility partners chosen platform
  - Period 3: Deliver demonstration vehicles (10 total) and perform 1 year demonstration and analysis

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Summary

- Odyne and its project partners are working towards greater acceptance, improved fuel savings, and increased ROI of the Plug-in Hybrid/Jobsite Electrification system for Medium- Heavy-Duty Work Truck through:
  - Increased Driving Fuel Economy
  - Algorithms and/or inputs to manage the drive / work energy balance
  - Improved Full Year Fuel Savings
  - Reduced system cost, system simplification

- Advancements have been made in the areas of:
  - Development of driving, stationary duty cycles and full-year model for the work truck
  - Lab results demonstrating the driving and stationary fuel and emissions improvements of the Odyne PTO based hybrid and electrifications system.
  - Development of a modular system approach to medium and heavy-duty vocational vehicle electrification

- Remaining Deliverables:
  - Analytical Demonstration of 50% reduction in Work Truck fuel use
  - Secure, Build and monitor the 10 vehicle demonstration fleet

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